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Identifying Suitable Watersheds across Nigeria Using Biophysical Parameters and Machine Learning Algorithms for Agri–Planning

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Abstract: Identifying suitable watersheds is a prerequisite to operationalizing planning interventions for agricultural development. With the help of geospatial tools, this paper identified suitable watersheds across Nigeria using biophysical parameters to aid agricultural planning. Our study included various critical thematic layers such as precipitation, temperature, slope, land-use/land-cover (LULC), soil texture, soil depth, and length of growing period, prepared and modeled on the Google Earth Engine (GEE) platform. Using expert knowledge, scores were assigned to these thematic layers, and a priority map was prepared based on the combined weighted average score. We also validated priority watersheds. For this, the study area was classified into three priority zones ranging from 'high' to 'low'. Of the 277 watersheds identified, 57 fell in the high priority category, implying that they are highly favorable for interventions. This would be useful for regional-scale water resource planning for agricultural landscape development.

Keywords: water; watershed proritization; agriculture; dryland; Google Earth Engine

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1. Introduction

The population of the world is projected to reach 10 billion by 2050, which means that we will require a higher rate of food production than we have now (World Population Data Sheet 2020). In Nigeria, the rapidly expanding and urbanizing population—which is expected to more than double in the next 35 years—has long exceeded domestic food production capability [1,2]. This makes it imperative that activities that help in attaining a high rate of food production and food self-sufficiency are more sharply focused. As part of the efforts needed to regain food self-sufficiency, Natural Resource Management (NRM) development programs must be conducted at the watershed level [3]. Moreover, there should be a focus on the fundamental principles of land and water resources management, such as watershed development and development of catchments and sub-catchments, which are critical to securing Nigeria's environmental and agricultural resilience [4]. Presently, irrigation covers only 7% of the irrigable land in Nigeria [1]. While rapid expansion of agricultural capacity, including through private investment [2], is indeed making more lands productive as an objective toward bridging the food deficit, there are warning signals like drought, gully formation, overgrazing, and erosion that need to be taken into account in agricultural initiatives across Africa (World Bank 2012). Identification of hotspots integrating various parameters like population, land-use/land-cover (LULC), and drainage networks can lead us to better solutions in agricultural development [5,6]. This approach takes into account the possible social aspects of the challenge too. Further, running decision tools can give satisfying results by aiding decision-making in relation to the implementation and development of natural resources. However, NRM has thus far been poorly implemented for agriculture development as well as for water supply. While Africa has rich natural resources and Nigeria has abundant water resources, there is an absence of efficient use of such resources. Preparation of watershed prioritization maps can help us enhance efficient utilization of natural resources, which currently are largely untapped in Nigeria [7].

Characterization of natural resources needs multidisciplinary investigations carried out by experts from different areas of expertise. In the present study, we prioritized watershed areas based on different biophysical parameters, such as population, soil, precipitation, landscape, LULC, and social parameters. Climate parameters, such as temperature and precipitation, highly influence the performance of watersheds: Low and very high rainfall negatively affects agriculture, as do extremes of temperature. Moderate climatic conditions are better for rainfed agriculture. In general, land resource management acknowledges the association between social and biophysical factors in attaining satisfying results [8–11].

Several studies have used the approach of integrating various thematic maps using geospatial tools for locating potential groundwater zones [12–16]. Similarly, studies have also been carried out on aspects of natural resources and development planning using remote sensing and GIS technologies [14,17–22]. Using various biophysical, socioeconomic, and technical parameters with a multi-criteria approach, geospatial techniques have been widely used in the assessment of land suitability for prioritization [23–29]. Specifically, several studies have shown that the weighted sum method is the most efficient method for prioritizing watersheds in developing countries [5,30].

The purpose of prioritizing watersheds is to identify focus watersheds for restoration activities that can address their critical needs and for intervention planning. It is a useful tool for decision-makers as it combines all the necessary information and allows a comparison of watersheds within the same cluster. This approach allows researchers to develop a summary of the watersheds of interest by spatially locating them and obtaining relevant information about their vulnerability. This process can also help in locating multiple watersheds with regard to prioritizing watershed protection and restoration.

In this study, we conducted a prioritization of watersheds across Nigeria to support natural resource management and agricultural planning. We identified, on the basis of biophysical parameters, an optimum number of watersheds ranging from low to high priority so that specific watersheds could be targeted for interventions. Further, with the help of geospatial inputs, thematic spatial data layers were used to construct a spatial model. We identified priority watersheds by allotting different weights based on the opinion of subject matter specialists (SMS). This scientific approach allowed us to prioritize watersheds strategically using multiple biophysical parameters at a time. This high-precision technique helps in delineating watersheds with utmost care and confidence.

2. Materials and Methods

2.1. Study Area

Nigeria lies between latitudes 4° N and 14° N and longitudes 4° E and 15° E. It is bordered on the north, east, west, and south by the Republic of Niger, the Republic of Benin, Cameroon, and the Gulf of Guinea, respectively (Figure 1). This location in West Africa gives the country a very wide range of climatic patterns. According to Odekunle (2004), Nigeria's climate is dominated by the influence of three major atmospheric phenomena: Maritime tropical (mT) air mass, continental tropical air mass, and equatorial easterlies. Rainfall varies within the country with a mean annual rainfall in the range of 1000–2000 mm in humid areas and 300–1100 mm in semi-arid areas. There is a slight variability of climate from south to north. In the north, the mean maximum temperatures are higher (32 °C) than in the south, while the mean minimum temperatures are lower (24 °C). As per the FAO's soil taxonomy, the major soil types in Nigeria are Fluvisols, Regosols, Gleysols, Acrisols, Ferrasols, Alisols, Lixisols, Cambisols, Luvisols, Nitosols, Arenosols, and Vertisols with varied potential for agricultural use. The Niger and Benue rivers are the major rivers in Nigeria. The Niger River has an irrigation potential of 1.68 million hectares (Mha) in Nigeria, but its use is limited to only 0.68 Mha. The country has six distinct agroecological zones varying from the Atlantic coast to the arid savanna of the Sahel. The major staple crops in the humid parts of Nigeria are cassava, yam, cocoyam, and maize, whereas in the subhumid and semi-arid parts, maize, sorghum, millet, cowpea, and groundnut are grown. The major commercial crops include cocoa, oil palm, cotton, ginger, and sesame.

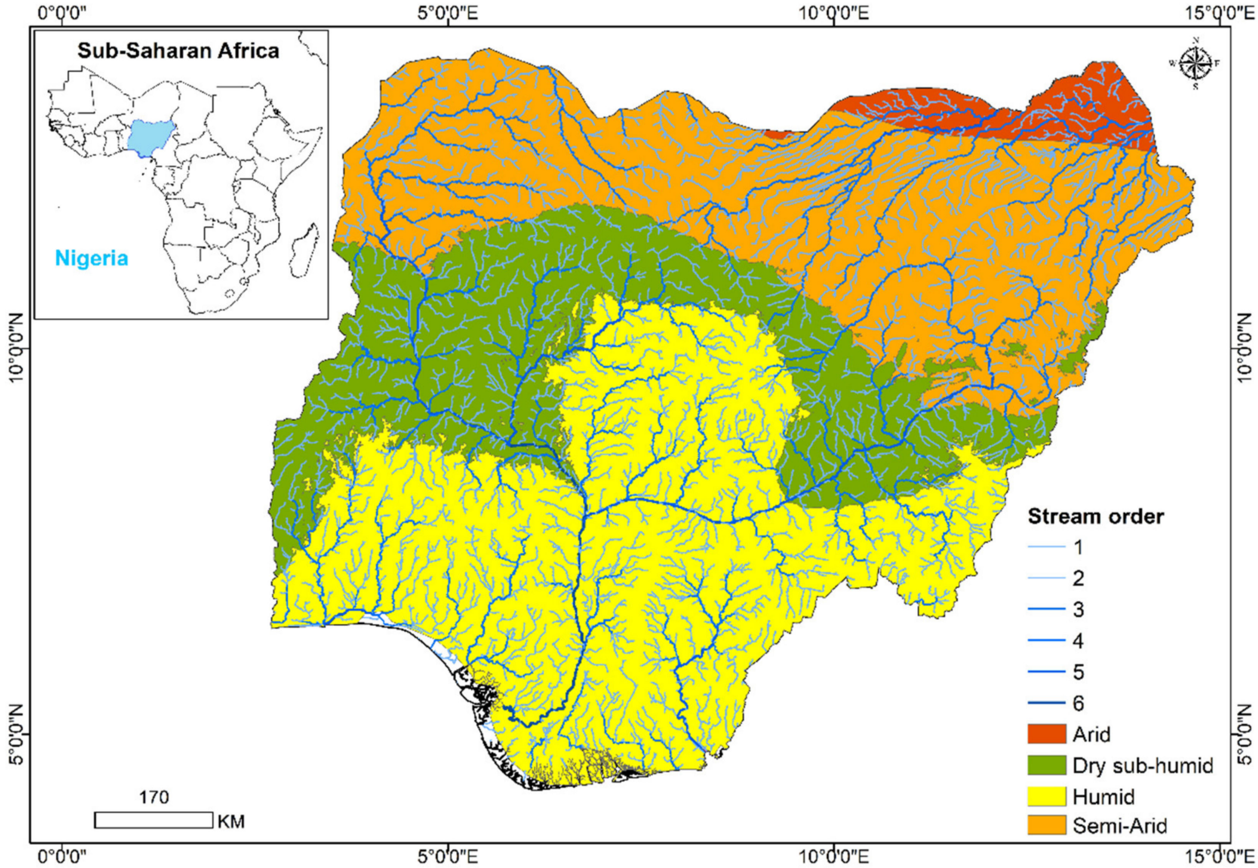

Figure 1. Location map of Nigeria with stream networks and agroecological zones (FAO).

2.2. Methodology

For identifying priority watersheds, we applied the methodology of weighted integration of multiple thematic layers using the geographic information system (GIS) (Figure 2). We used thematic spatial layers of both biophysical and social parameters that are important for agriculture. The priority order, i.e., ranking, of every spatial layer was obtained from subject matter experts, including NARS scientists in Nigeria. The priority classes were decided on the basis of the multi-criteria decision rule.

For thematic layers, such as LULC, a map of the year 2014 was prepared from MODIS 250 m satellite imagery using Normalized Difference Vegetation Index (NDVI) time-series data. The slope map was prepared from SRTM 30 m data. Similarly, other thematic spatial layers were acquired from the public domain using Google Earth Engine. The weightage and scores for the values in the thematic layers were given in relation to their positive effect on watershed and agricultural development. Thematic layers with a high positive value were given the highest weightage and vice versa. Upon integration of multiple spatial layers, the sum of all weights was calculated. High priority was given to the thematic layer that obtained the highest score and vice versa.

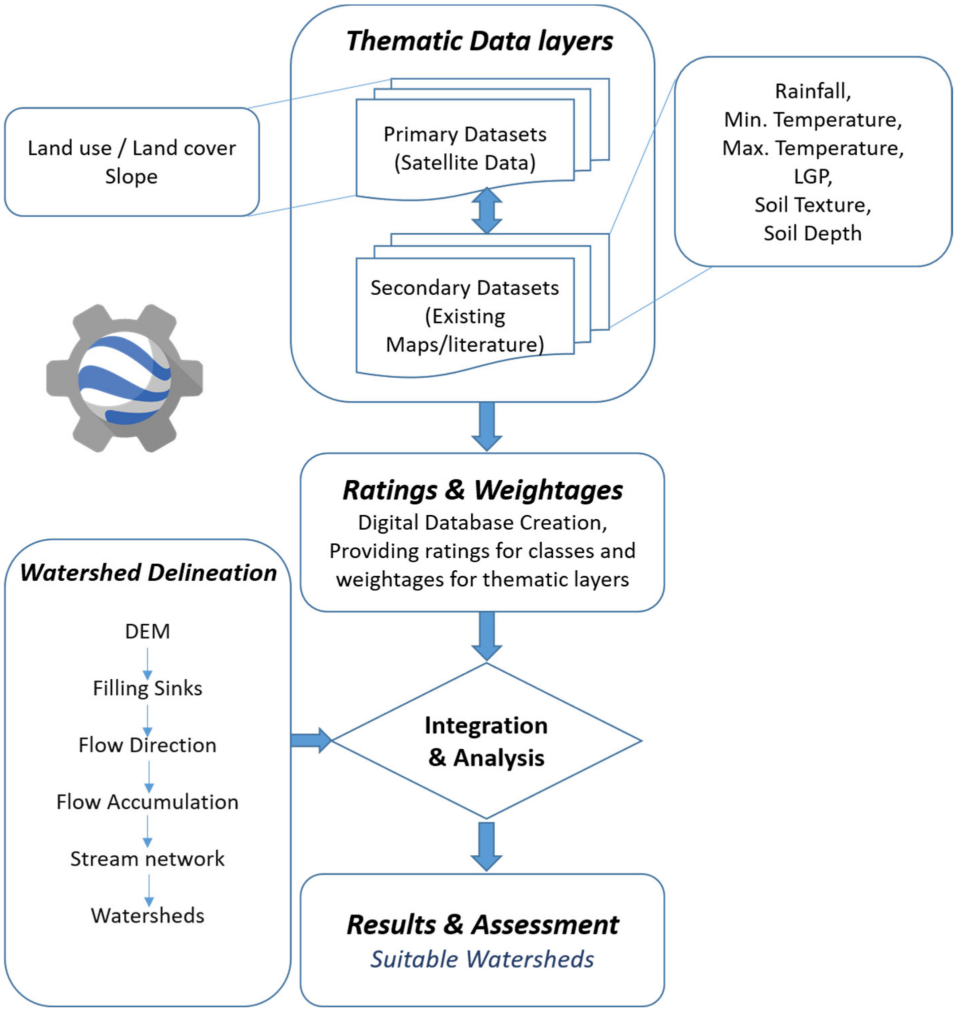

Figure 2. Methodology of watershed prioritization using geo-spatial layers.

2.3. Criteria and Determining Factors

Various thematic layers, such as soil, slope, LULC, rainfall, maximum and minimum temperature, length of growing period (LGP) (see Appendix A) were considered for the prioritization analysis based on their importance and relationship with other thematic layers. Based on the rating given by subject matter experts, the criteria to define prioritization was the sum of weights for all thematic layers (Table 1).

Table 1. Priority levels for thematic layers.

Suitability Criteria	Priority Level		
	Low (1)	Moderate (2)	High (3)
Average min. temp (°C)	0–15	15–20	20–25
Average max. temp (°C)	Up to 20 and >40	20–30	30–40
Average precipitation (mm)	Up to 250	250–1000	>1000
Slope (% rise)	>20	5–20	<5
Soil texture (class values)	5, 6, 8	2, 3, 4, 7	1
Soil depth (mm)	<5	5–20	>20
LGP (No. of Days)	>240	150–240	60–150

2.3.1. Land-Use/Land-Cover

Land-use/land-cover (LULC) patterns were mapped for the year 2014 using MODIS 250 m resolution satellite imagery, targeting major land-use classes like croplands (Figure 3), shrub lands, water bodies, and built-up/open lands [31,32]. Among these LULC classes, the dominant class with the highest score was cropland. Rainfed croplands were chosen rather than irrigated cropland because of their higher priority in watershed development. Classes like built-up land and water bodies were given less priority, whereas shrub lands and grassland were given medium priority because of their vegetation status. The LULC layer was assigned the weightage of 3.

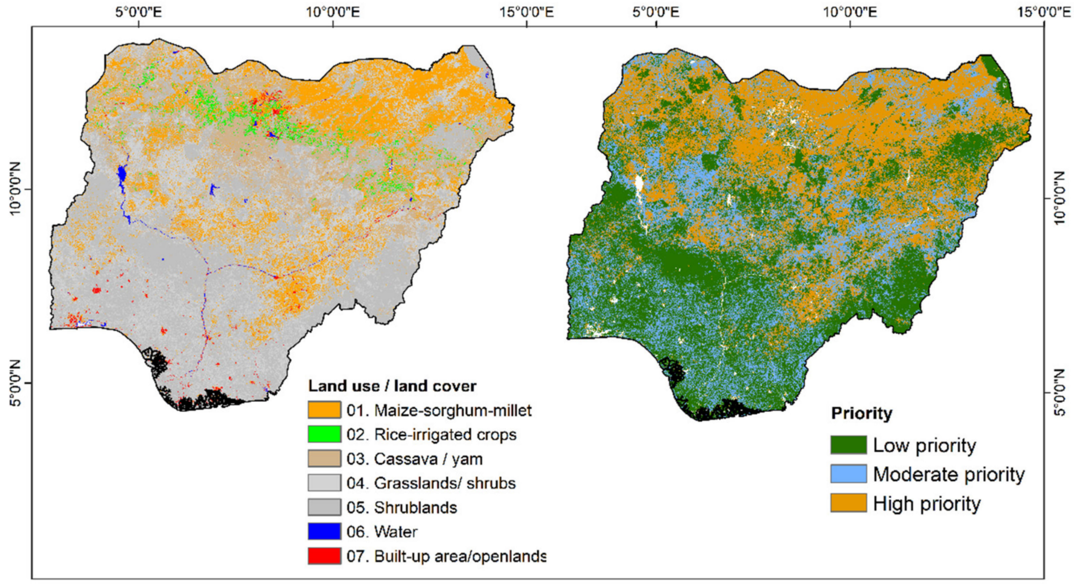

Figure 3. LULC classes in Nigeria.

2.3.2. Slope

The slope map was derived from SRTM 30 m DEM data (Figure 4). The map was stratified in terms of percentage change showing the rise or fall of land surface, which is a crucial factor in determining water flow. Lower percent change of elevation, i.e., slope, was given a high priority because of ease during cultivation and high groundwater potential. High percent change was given low priority in the estimation. This layer was given a low weightage of 1.

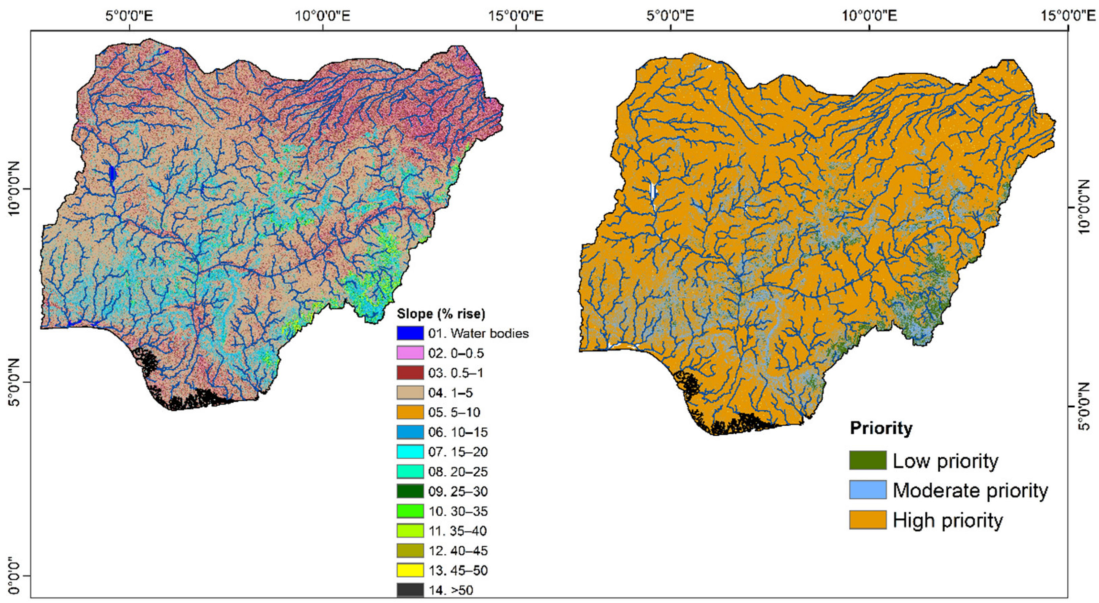

Figure 4. Slope map of Nigeria (SRTM DEM: http://srtm.sci.cgiar.org/) (accessed on 11 January 2022).

2.3.3. Soils

Soil parameters [33] (soil texture and soil depth) play a vital role in watershed prioritization because of their critical role in runoff. The water withstanding capacity of a location depends upon the soil type/texture and permeability at that location. The experts' scores were assigned for both layers, i.e., soil texture and soil depth, based on priority. Soil texture was classified into eight types (clay, clay loam, loamy sand, loam, sand, sandy clay loam, sandy clay, and sandy loam). Clay soils were given high priority, and sandy soils were given low priority (Figure 5a). Soil depth was classified into six classes (Figure 5b). Deeper soils were given a higher priority than lower-depth soils. These layers were assigned a weightage of 3.

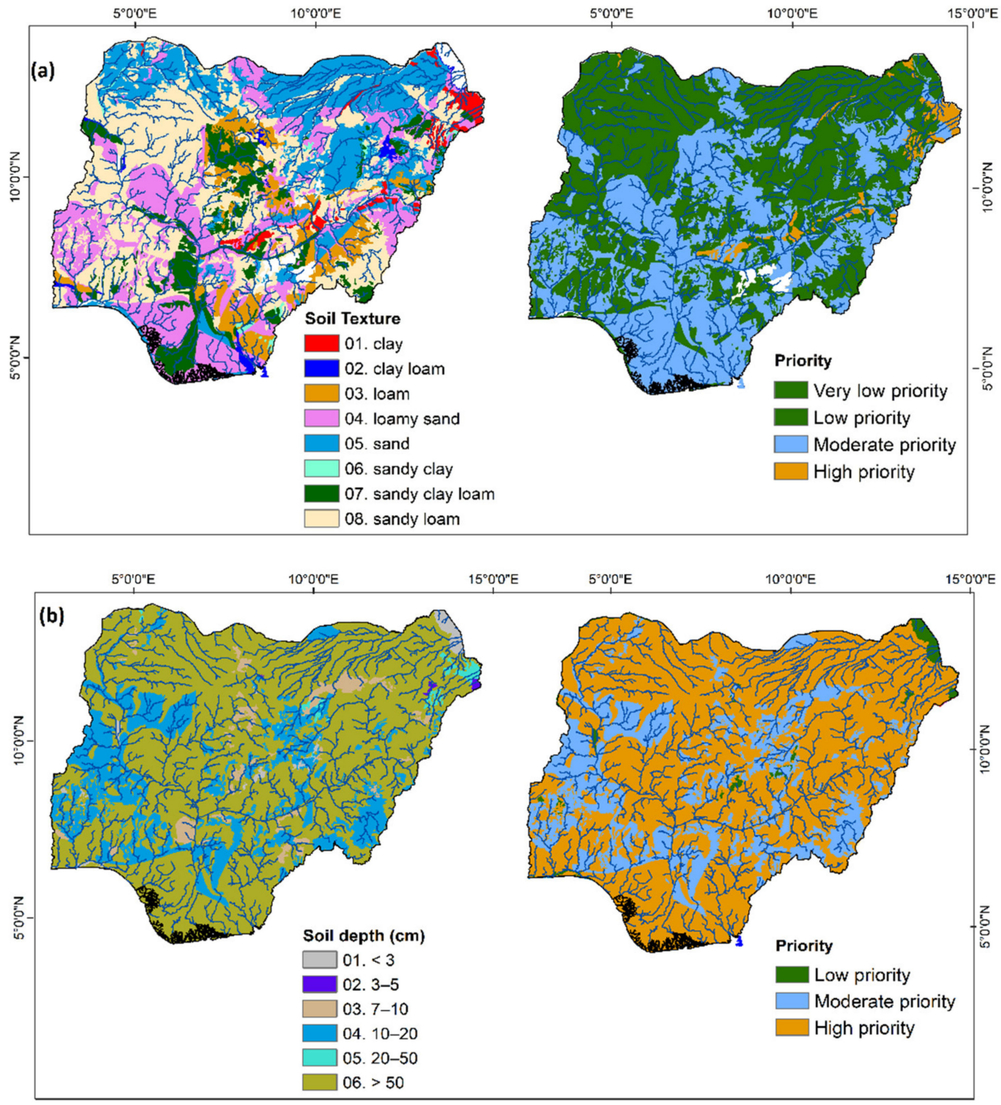

Figure 5. (**a**) Soil texture and its priority map and (**b**) soil depth and its priority map.

2.3.4. Rainfall

The annual rainfall data (2010–2018) were downloaded from Terra Climate [34] (Figure 6). Average rainfall was classified into 10 classes. The areas receiving less than 250 mm of rainfall were given a low priority and areas with rainfall greater than 1000 mm were given high priority, and medium range of rainfall was allotted moderate priority. A weightage of 3 was given to this layer.

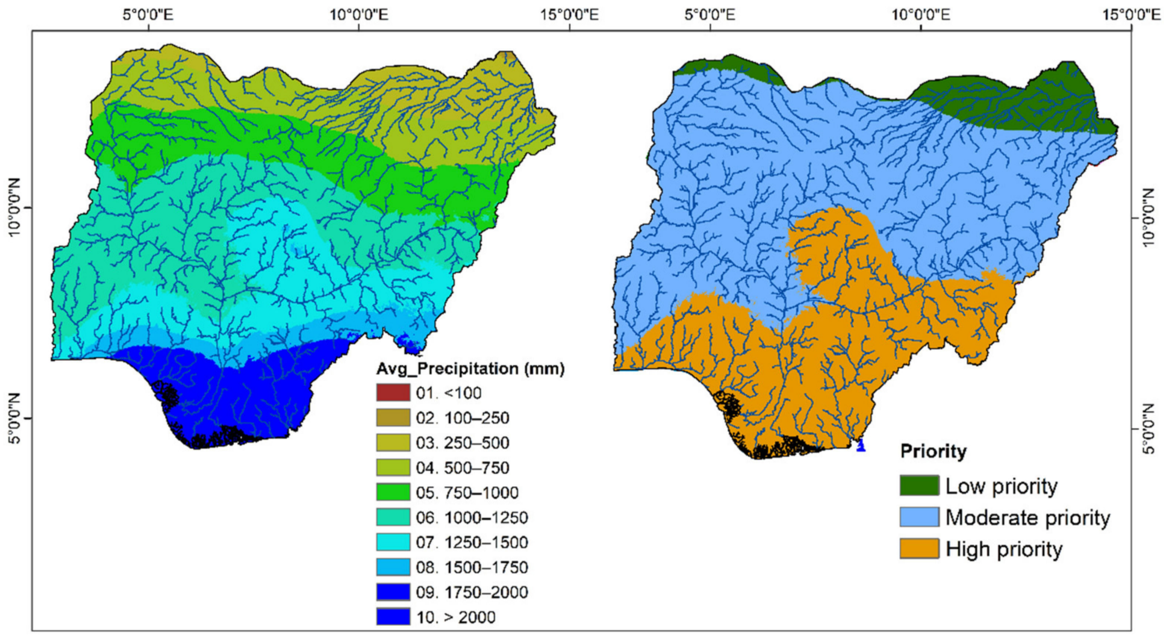

Figure 6. Mean annual rainfall in Nigeria (TerraClimate).

2.3.5. Length of Growing Period (LGP)

The length of the growing period (LGP) is one of the factors that determine the vegetation in an area in a year [35]. LGP was classified into seven classes in which two classes, <60 days and >240 days, were given low priority, while the LGP class 60–150 days was given high priority and 150–240 days moderate priority (Figure 7). A weightage of 2 was given to this layer. The LGP product was prepared by FAO as a part of the World Bank's review of its rural development strategy. It was prepared using vegetation indices as well as annual rainfall.

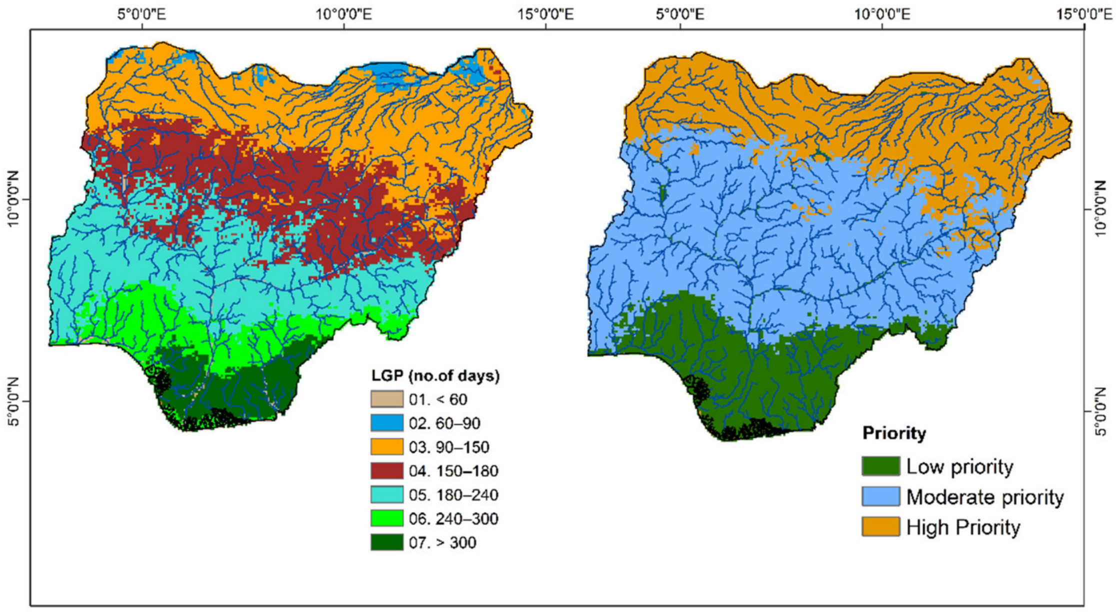

Figure 7. Length of the growing period (LGP) in Nigeria.

2.3.6. Temperature

Minimum temperature: Average minimum temperature data were downloaded from WorldClim and classified into four classes with 5 °C intervals (Figure 8a). The areas with an average minimum temperature <5 °C were allotted a very low priority, and those between 5 and 15 °C were given low priority. Areas with average minimum temperatures between 20 and 25 °C were given a high priority, whereas those with 15–20 °C were assigned moderate priority. This layer was given a weightage of 2.

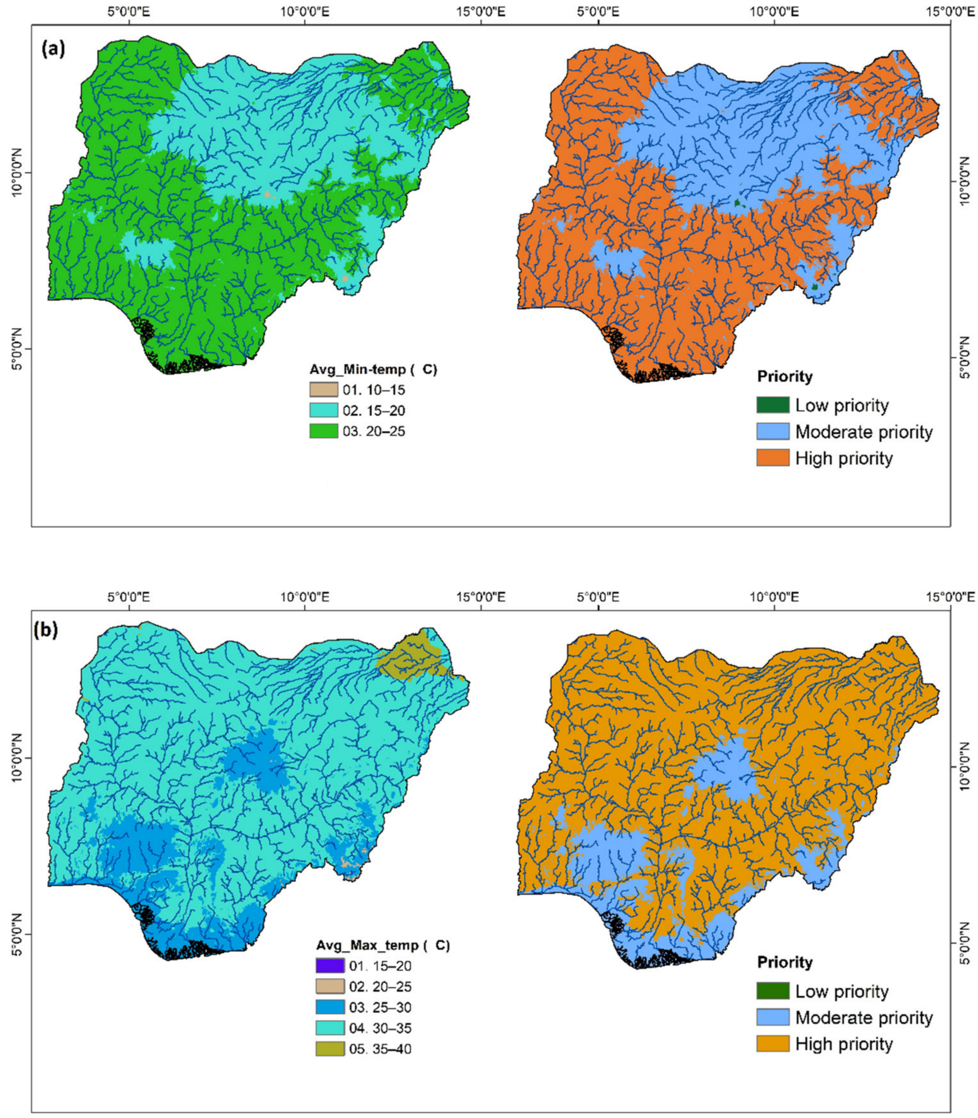

Figure 8. (**a**) Average annual minimum temperature and it priority map. (**b**) Average annual maximum temperature and its priority map.

Maximum temperature: Average maximum temperature data were downloaded from WorldClim and classified into six classes (Figure 8b). Areas having a mean maximum temperature of <20 °C or >40 °C were given low priority. Those areas with a mean maximum temperature of 20–30 °C were given moderate priority, whereas areas with maximum temperature varying in the 30–40 °C range were given a high priority. This layer was given a weightage of 3.

2.4. Determining Thematic Layer Weights

On the basis of expert/scientists' knowledge and a review of published papers [8,14,16,36,37], weights were allotted to different layers. The layers most favorable to watershed interventions were those that received a high weightage of 3. The layers least favorable to interventions were those that had a weightage of 1, while a weightage of 2 indicated moderately favorable layers. Layers like average annual maximum temperature, annual average precipitation, LULC, soil texture, and soil depth were given a high weightage of 3.

Annual average minimum temperature and LGP were given a weightage of 2. The slope map was given a low weightage of 1.

2.5. Integration of Thematic Layers Using Spatial Models

The integration of these thematic layers was carried out by developing a spatial model on GEE. The classes within each layer were reclassified on the basis of their scores given by experts (Equation (1)). Then, using the raster calculator, the weightages given by experts were multiplied by the respective layers (Equation (2)).

$$T_{sw} = T_r \times W \tag{1}$$

T_{sw} = Thematic layer with weighted score
T_r = Reclassified thematic layer
W = Weights

Then, all the weighted thematic layers were summed up and integrated to get the priority map

$$P_m = \Sigma T_{sw} \tag{2}$$

P_m = Priority map

2.6. Spatial Modeling Using Machine Learning Algorithms on Google Earth Engine Platform

Layers such as rainfall and temperature from WorldClim and slope maps from SRTM DEM were available on the GEE platform. Other layers, such as LULC, LGP, and soil maps, were ingested into GEE assets.

The layers were reclassified using decision tree algorithms incorporating the expert-given values using code as in the example below.

Example for rainfall reclassification:

```
"
var DTstring_prep =
['1) root 9999 9999 9999', '2) prec<=250 9999 9999 1 *',//Allocated value 1
'3) prec>250 9999 9999 9999', '6) prec<=1000 9999 9999 2 *',//Allocated value 2
'7) prec>1000 9999 9999 3 *'].join("\n"); Allocated value 3
var classifier_prep = ee.Classifier.decisionTree(DTstring_prep);
var reclassifiedImage_prep = prep.select('prec').classify(classifier_prep);
"
```

In the above example of a decision tree algorithm, it reclassified pixels with a value <250 m as 1, whereas values between 250 and 1000 mm were reclassified as 2 and those >1000 mm were 3.

A similar procedure was used for all the layers by giving scores to the respective pixels that are favorable to watershed interventions. The weightages are then multiplied with the scores of respective layers as per expert opinion and were summed up as in the example below.

For example:

```
"var weighted=
reclassifiedImage_minTem.add(reclassifiedImage_maxTem).add(reclassifiedImage_slop).add
(reclassifiedImage_prep)
"
```

The above example shows the addition of the reclassified layers of minimum temperature, maximum temperature, and precipitation. Then, the summed-up layer is reclassified as per priority, low, medium, or high, based on the values attained by each pixel.

2.7. Watershed Delineation

The major input data for delineating the watersheds were drawn from SRTM 30 m horizontal resolution DEM obtained from the web portal of the Consortium for Spatial Information [38] (http://srtm.csi.cgiar.org/) (accessed on 11 January 2022). These data were utilized to delineate the stream network and the slope map using ArcGIS tools. The sequence of steps followed to delineate the stream network, as well as watersheds, is illustrated in Figure 2.

The process starts with filling the sinks by comparing the values of neighboring cells. The filled sinks help in the generation of flow direction by finding the steepest descent of every cell. Then, flow accumulation is calculated using flow direction by counting the number of cells that are flowing to a particular cell. A set of thresholds for flow accumulation and flow direction generates the stream network.

The generation of pour points at the sixth stream order for the entire study area helps in the generation of watersheds (Figure 9a,b).

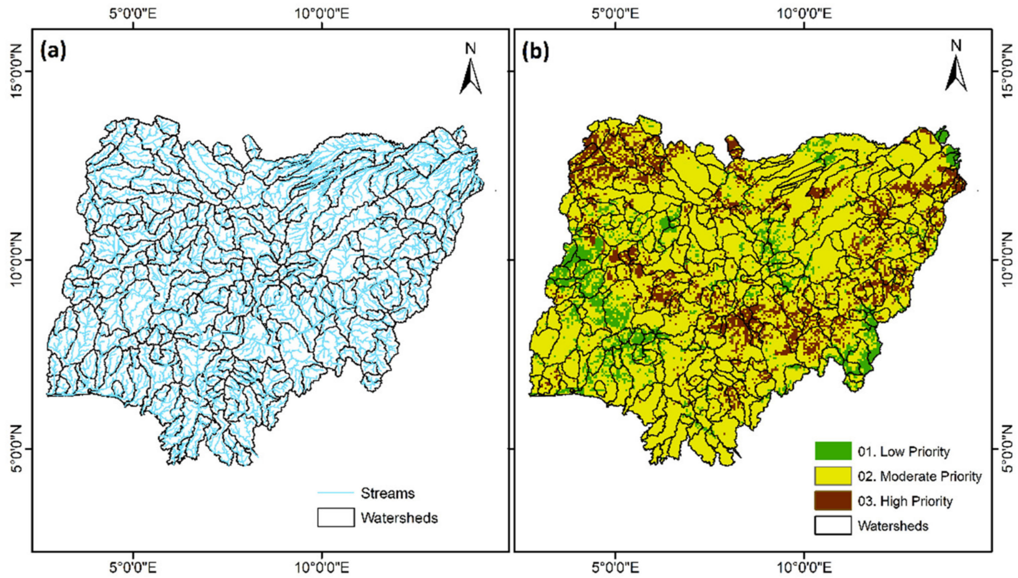

Figure 9. (**a**) Watershed and stream network delineation in Nigeria. (**b**) Spatial distribution of watersheds and their priority in Nigeria.

3. Results and Discussion

3.1. Watershed Analysis and Prioritization of Watersheds

Among all the watersheds identified throughout Nigeria, 277 were identified as having an area greater than 100 ha. Out of these, 144 watersheds were found to have an area less than 0.2 Mha, 71 were in the range of 0.2–0.4 Mha, and 26 in the range of 0.4–0.6 Mha. Only about 30 watersheds have an area greater than 0.6 Mha (Table 2).

Table 2. Area-wise classification of watersheds in Nigeria.

Area (Mha)	No. of Watersheds
<0.2	144
0.2 to 0.4	71
0.4 to 0.6	26
0.6 to 0.8	15
0.8 to 1.0	8
1.0 to 1.2	6
1.2 to 1.4	3
1.4 to 1.6	2
>1.6	2

The watershed prioritization map of Nigeria was derived after integration of the allocated priority values for different thematic layers. The priority map was categorized into three classes: High, moderate/medium, and low priority. The areas identified as high-priority are very favorable to watershed development, and the low-priority zones are the least favorable. Most of the watersheds in Nigeria fell in the moderate-priority class. The defined watershed map of Nigeria was overlaid on the priority map to identify strategic watersheds for agricultural development (Figure 9a,b).

3.2. Integration of Watershed Map with Thematic Layers

For a more detailed understanding of the watersheds, priority maps were prepared as per each thematic layer (Figure 10a–g). Table 3 shows the number of watersheds in every thematic category.

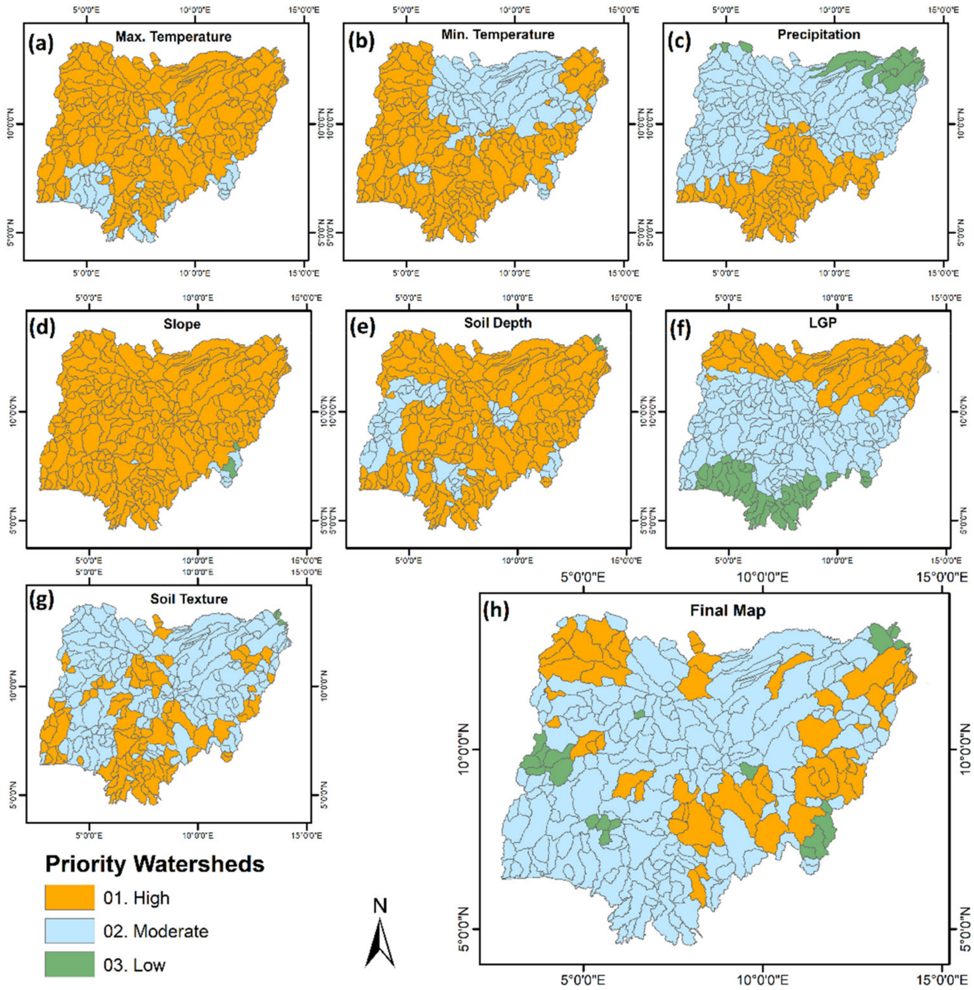

Figure 10. (**a**–**g**) Prioritized watershed maps as per thematic layer. (**h**) Prioritized watersheds after integration of all thematic layers in the study area.

The watershed map with the integration of all thematic layers is shown in Figure 10h. Considering only the precipitation layer, we found that only 98 watersheds had highly suitable rainfall conditions, which is a crucial layer for agriculture planning. About 159 watersheds fell in the moderate-priority class. For maximum and minimum temperature, almost all watersheds had moderately suitable or highly suitable conditions. Soil conditions too showed a favorable tendency. These findings show the importance of watersheds in this country.

Table 3. Number of proritized watersheds by thematic layer.

Thematic Layers	Number of Watersheds		
	Low Priority	**Moderate Priority**	**High Priority**
Maximum temperature	0	47	230
Minimum temperature	0	98	179
Precipitation	20	159	98
Slope	2	6	269
Soil depth	6	59	212
Soil texture	5	153	119
LGP	51	148	78
Final map	21	199	57

3.3. Validation of Priority Watersheds

On the basis of the available data, we validated the priority watersheds in relation to dams constructed in Nigeria (Figure 11). The details of dams and their purpose are illustrated in Table 4.

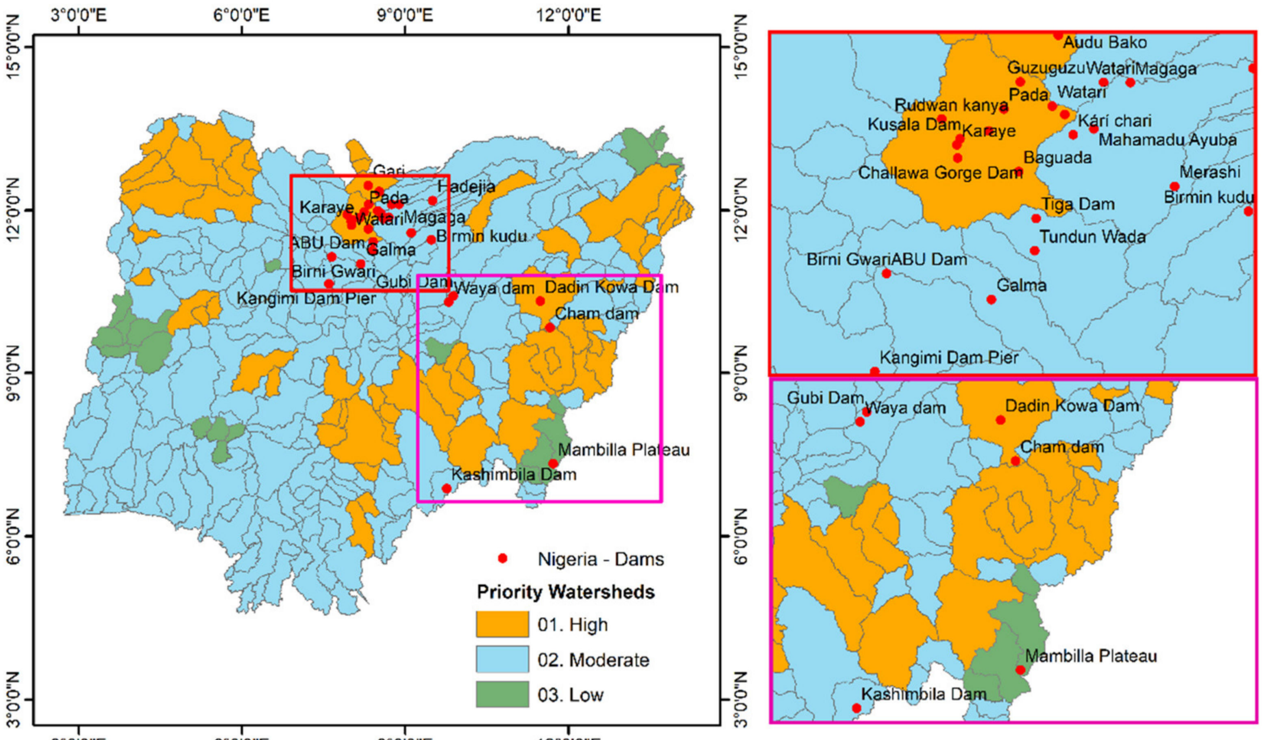

Figure 11. Map showing the location of dams in Nigeria.

We found that most of the dams constructed for the purpose of irrigation lie within moderate and high-priority watersheds. Dams constructed for multiple purposes, such as irrigation, as well as hydroelectric power generation, were mostly in moderate-priority watersheds, whereas dams located within high-priority watersheds were those built only for irrigation. The Mambila Plateau dam constructed for hydroelectric power generation lies in a low-priority zone. This validation indicated that the study correctly prioritized watersheds for agricultural planning and development.

Table 4. Locations of dams and their purpose.

FID	Long.	Lat.	Name	Objective	State	Priority
0	8.52168	12.340262	Audu Bako	Irr/ws	Kano	High
1	8.319344	12.449709	Gari	Irr/ws	Kano	High
2	8.750295	12.101573	Watari	Irr/ws	Kano	Moderate
3	8.026064	11.816966	Kusala Dam	Irr/ws	Kano	High
4	8.013794	11.719821	Challawa Gorge Dam	Irr/ws	Kano	High
5	8.55439	11.939492	Adu Bayero	Irr/ws	Kano	High
6	8.32209	11.650109	Baguada	Irr/ws	Kano	High
7	8.010376	11.785614	Karaye	Irr/ws	Kano	High
8	8.491756	11.982099	Watari	Irr/ws	Kano	High
9	8.170203	11.856063	Tomas dam	Irr/ws	Kano	High
10	7.933704	11.915973	Rudwan kanya	Irr/ws	Kano	High
11	8.2476	11.967202	Pada	Irr/ws	Kano	High
12	8.329988	12.10452	Guzuguzu	Irr/ws	Kano	High
13	9.50311	12.173312	Hadejia	Irr	Jigawa	Moderate
14	8.701458	11.866207	Mahamadu Ayuba	Irr/ws	Kano	Moderate
15	9.108804	11.575692	Merashi	Irr/ws	Kano	Moderate
16	8.885244	12.100326	Magaga	Irr/ws	Kano	Moderate
17	9.481497	11.450196	Birmin kudu	Irr/ws	Jigawa	Moderate
18	8.409686	11.413934	Tiga Dam	Irr/ws	Kano	Moderate
19	8.402408	11.25013	Tundun Wada	Irr/ws	Kano	Moderate
20	8.184803	11.004238	Galma	Irr/ws/HP	Kaduna	Moderate
21	7.6548271	11.135078	Birni Gwari	Irr/ws	Kaduna	Moderate
22	7.6548271	11.135078	ABU Dam	Irr/ws	Kaduna	Moderate
23	7.596162	10.639892	Kangimi Dam Pier	Irr/ws	Kaduna	Moderate
24	9.881125	10.418291	Gubi Dam	Irr/ws	Bauchi	Moderate
25	9.80136	10.30249	Waya dam	Irr/ws/HP	Bauchi	Moderate
26	11.481694	10.322154	Dadin Kowa Dam	Irr/ws/HP	Gombe	High
27	11.6613	9.8329	Cham dam	Irr/ws	Gombe	High
28	11.72	7.33	Mambilla Plateau	HP	Taraba	Low
29	9.761765	6.873387	Kashimbila Dam	Irr/ws	Taraba	Moderate

Irr = Irrigation; ws = Water Supply; HP = Hydroelectric power.

4. Discussion

Natural resource management plays a crucial role in the sustainable utilization of the available natural resources. In the context of watershed management, prioritization of watersheds helps in the effective use of natural resources for agricultural development in a shorter period of time. Watershed prioritization using remote sensing and GIS techniques is an easy and convenient approach based on weighted scores provided by SMS/scientists. In past studies, watershed prioritization was carried out using quantitative analysis, statistical methods, fuzzy and AHP techniques [39–41], morphometric analysis [42], delineation of groundwater potential zones [43], prioritization of sub-watersheds [44,45], prioritization of semi-arid agricultural watersheds [46], spatial assessment of soil erosion risk [47,48], and many other parameters. Our study considered biophysical parameters and major LULC classes to carry out watershed prioritization in Nigeria as a tool for agricultural development and planning. These parameters included average minimum temperature, average maximum temperature, average precipitation, slope, soil depth, and length of the growing period, which have a major role in watershed development and management. Analyzing these biophysical parameters and rating them with the help of subject experts, we carried out prioritization of watersheds in Nigeria using SRTM DEM-delineated data. Various studies have employed different methods of watershed prioritization for expansion of agriculture [5,49], critical sub-basins in mountainous watersheds [50], natural resource management [40,51], sediment yield index [52], LULC change impacts [53], assessment of flash flood risk with the help of weighted-sum models [54], etc. However, in all these methods, prioritization of watersheds was analyzed based on individual biophysical parameters such as topographical information, LULC, weather data, soil texture, soil depth and slope, etc. Nevertheless, the multi-criteria decision-making approach depends on the total score obtained after applying each thematic layer, and the accuracy of analysis of each input parameter.

It is very important to identify high-priority watersheds in Africa as land resource development programs are generally designed on a watershed basis. Therefore, appropriate prioritization is required for proper intervention and management. In our study, based on priority classification for every parameter, priority-wise watersheds were delineated and mapped. This helps various stakeholders in making decisions appropriate to their requirements. Various stakeholders in Nigeria will significantly benefit from the findings of this study. Integration of slope, soil depth, and soil texture maps and prioritization on the basis of those parameters should help in planning for soil conservation measures and watershed interventions. The maximum and minimum temperature layers in our study indicate the direct or indirect effects on soil moisture as well as evapotranspiration [55]. Prioritization of watersheds as per the precipitation layer clearly indicates the water-sufficient and water-deficient areas. Flood-prone and drought-prone watersheds can also be identified by considering the relevant parameters. Prioritization of watersheds in terms of the LGP indicated the vegetation levels throughout the year. Every parameter has a favorable and non-favorable relation with the watershed. Some parameters positively impact the watershed and others negatively. The integration of all such parameters can provide insights to mitigate risks. Integration of all parameters in a systematic and scientific manner can help in precise targeting of watershed interventions and agricultural development plans.

High-priority and moderate-priority watersheds are the best-suited sites for NRM interventions, such as construction of water structures, whereas low-priority areas have less a suitable environment potential for agricultural development. High-priority watersheds are highly suitable for constructing structures for irrigation, whereas moderate-priority watersheds can be utilized for multipurpose projects. Low-priority watersheds can be used for other purposes. The identification and delineation of such watershed areas help in better agricultural development planning, as well as implementation of appropriate interventions.

5. Conclusions

Identifying watersheds suitable for interventions is important for efficient utilization of natural resources. Prioritization is an important step for efficient natural resource management and increasing crop-water productivity. Using data generated from satellite imagery and information adapted from available open-source global data sets and national sources, we prepared spatial maps of watersheds in Nigeria. From this, we identified and prioritized suitable watersheds across the country for better agricultural, as well as livelihood, development. We integrated thematic layers prevailing in these watersheds and gave weighted scores to them with the help of experts and published papers. By the integration of these weighted layers, we generated a priority map of watersheds in Nigeria. The analysis showed that most of the areas in Nigeria fall in the class of moderate priority. Higher-resolution datasets can further improve these maps, and the method can be applicable to small areas to implement watershed interventions.

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Appendix A

Table A1. Parameters related information and their sources.

Variable	Year	Type	Resolution	Source
Maximum Temperature	2010–2018	Raster	~4 km	TerraClimate
Minimum Temperature	2010–2018	Raster	~4 km	TerraClimate
Precipitation	2010–2018	Raster	~4 km	TerraClimate
Slope	2014	Raster	90 m	SRTM
Soil	1994	Vector	1:5,000,000	FAO [33]
LULC	2014	Raster	250 m	LULC [31]
LGP	2011	Raster	8 km	LGP [35]

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